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(54) **Catadioptric objective comprising two intermediate images**

(57)   A catadioptric objective of axial symmetry with two intermediate images achieving high resolution and to be used advantageously in the VUV region for microscopy or microlithography. The objective comprises a first refractive partial objective (S1) which generates a first intermediate image in the central bore of a mirror (M2), a catadioptric second partial objective (S2) which generates a second intermediate image in the central bore of a mirror (M1) and a third refractive partial objective (S3) which generates the final image (Im).

FIG. 1

125 mm

EP 1 098 215 A1
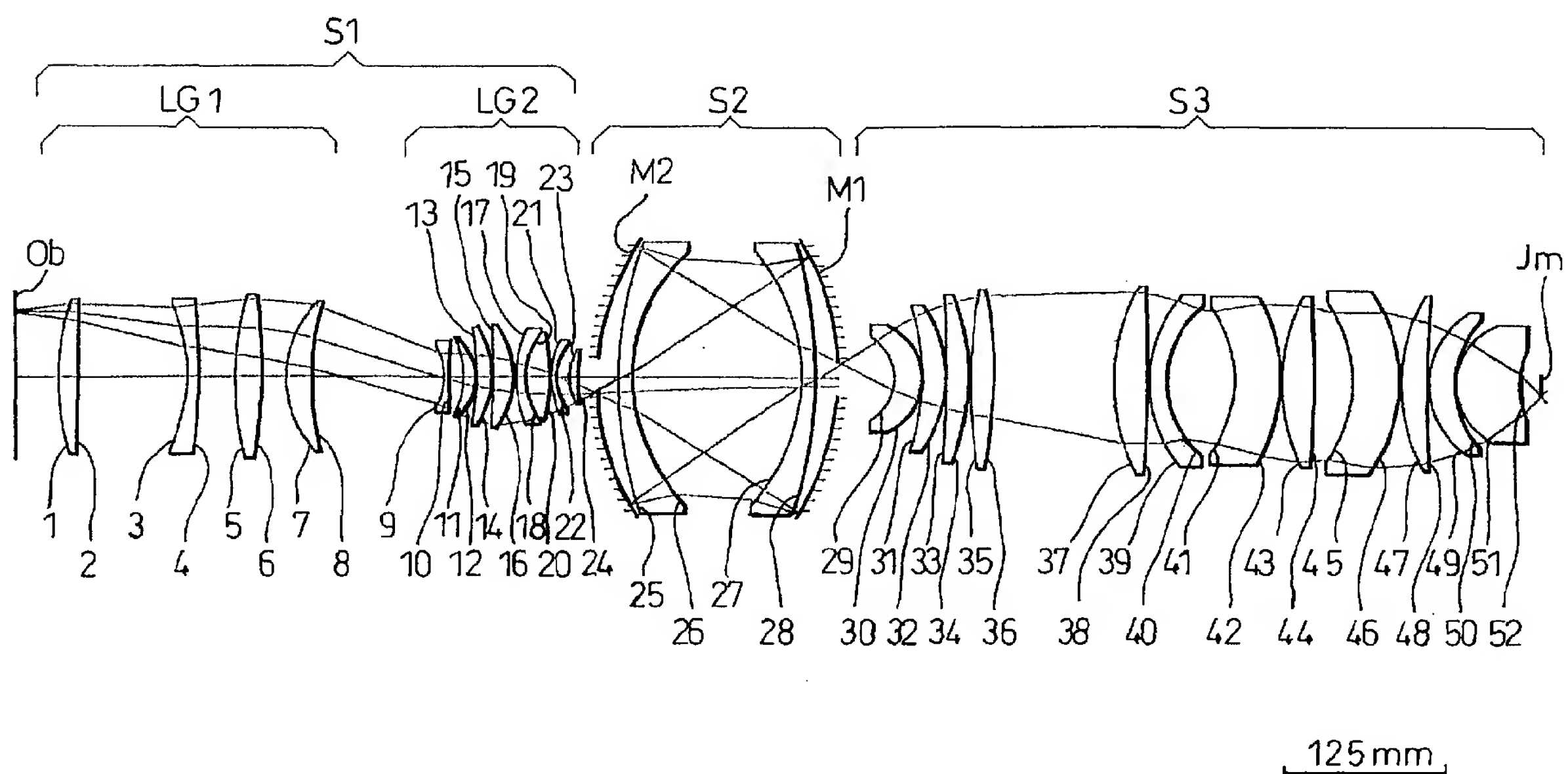
Description

[0001]   The invention is related to a catadioptric objective comprising two intermediate images.

[0002]   Such is known from US 4,701,035 to Hirose as a microlithographic projection exposure system. The objective shown there in Fig. 12 comprises two catoptric partial objectives and one catadioptric partial objective. All objectives are off-axis, not axially symmetric, purely spherical systems.

[0003]   Catadioptric objectives with one intermediate image and a refractive partial objective are known as micro-lithographic projection systems with axial symmetry and central obscuration from US 5,488,299 to Elliott and Shafer and from DE 196 39 586 (US ser. No. 09/263,788) to Schuster, the latter being assigned to the assignee of this invention, and incorporated herein by reference.

[0004]   Elliott and Shafer show the intermediate image near to the central opening of one of the mirrors, and lenses are arranged in the light path between the mirrors forming Mangin mirrors.
All their optical surfaces are spherical.

[0005]   Schuster shows only the mirrors to be aspherical and avoids big lenses in the beam path between them.

[0006]   US 5,004,331 to Haseltine et al. discloses a catadioptric projector for projecting an image to a dome (of a flight simulator). The system comprises an external entrance pupil as means for receiving substantially collimated light, a refractive subsystem of rotationally symmetric, coaxial lenses forming a pupil image which is situated at the central opening of an aspheric concave mirror, which together with another concave mirror forms a reflective pupil relay system. Both mirrors are tilted with respect to the optical axis of the refractive subsystem. The whole system provides a wide field of view image on a spherical dome. Full visible spectrum colour correction is obtained by combination of different glass.

[0007]   It is an object of the invention to provide new design alternatives which allow for high resolution objectives with reduced lens diameters and high performance. Advantageously these designs are to be used in the VUV spectral region for microscopy or microlithography.

[0008]   The solution of this problem is obtained by the objective according to one of the claims 1 to 4.

[0009]   Axial symmetry together with two intermediate images, two refractive and one catadioptric partial objectives, two intermediate images and at least one refractive partial objective are varied descriptions of the novel aspects of the invention according to claims 1 to 3.

[0010]   Another aspect is given in claim 4 which clearly groups the mirrors in one catoptric partial objective, which cooperates with one or more purely refractive partial objectives. In this case it is provided that the catoptric partial objective carries the burden of Petzval sum reduction or field flattening. This relieves the refractive partial objective from the need for beam contractions and expansions by negative and positive lens groups, as is long established with microlithographic projection exposure lenses, see e. g. Glatzel E., ZEISS-Information 26 (1981), p. 8-13, US 5,260,832 or US 5,903,400. In consequence the refractive partial objective is simplified and the lens diameters are reduced. Especially for the proposed use in the VUV spectral region this gives great relief to the materials supply of suitable crystals or quartz glasses.

[0011]   Preferred embodiments and advantageous forms of the invention are subjects of the dependent claims 5 to 34. Namely, according to claim 5 the features given in the preceding independent claims are advantageously combined.

[0012]   The preferred embodiments also are related to the cited Schuster or Elliott and Shafer designs with two coaxial central obscuration opposing convex mirrors, which allows for a very convenient axial symmetric construction of the objective. Such inter alia has advantages in mechanical rigidity and in compatibility with established stepper/scanner architectures adapted to refractive objectives.

[0013]   As a central obscuration in principle has degenerating effects in imaging - though in many cases decidedly taken advantage of as in annular or quadrupole illumination or in pupil filtering and apodisation - the reduction of the obscuration by the central hole of the mirrors of this design is of importance.

[0014]   Claim 7 gives a preferred way of reducing obscuration by placing the intermediate images in the vicinity of the mirrors. Claims 10 and 11 give quantitative limitations of the central openings.

[0015]   Claims 8 and 9 show an alternative of claim 4, where lenses are inserted between the mirrors. As negative lenses these cooperate with the mirrors to give single material colour correction, relieving the need for band narrowing the laser light source or for using an achromatizing material pair in the VUV.

[0016]   According to claim 12 it is especially advantageous that the chief ray height at each of the mirror bores is approximately the same in value , but opposite in sign. This measure allows for minimal central obscuration.

[0017]   The sequence given in claim 13 where the mirror-containing partial objective is framed by the two refractive partial objectives is preferred as it allows for both intermediate image "planes" connected by the mirror containing partial objective to be curved such as to best exploit the specific correction capabilities of this partial objective.

[0018]   While it is rather conventional that mirrors are aspheric also in the related art, in claim 14 it is specifically stated that aspheric lens surfaces prove advantageous with this design. All advantages and restrictions as recently established for refractive projection exposure objectives, see e. g. patent application DE 199 22 209 of Schuster and

references cited therein, as incorporated herein by reference, hold also for the use of aspheric surfaces in the designs of this invention.

[0019] Claim 15 states that diffractive surfaces, as occasionally also proposed for projection exposure objectives, are also useful with this invention just as they are with refractive designs.

[0020] Other advantageous varieties and properties of the invention are subject of claims 16 to 30.

[0021] According to claims 31 and 32 such objectives are preferably part of microscope or a microlithographic projection exposure system. Claim 33 likewise gives the advantageous use of such objective for microlithographic projection exposure. Claim 34 gives an advantageous way of microlithography using an objective according to preceding claims.

[0022] The invention is described in more detail based on the examples shown in the drawings.

Fig. 1   shows the lens section of an example of an objective with a refractive, a catadioptric, a second refractive partial objective in sequence, reduction ratio 1 : 6

Fig 2   shows another example of such an objective with reduction ratio 1 : 5

Fig 3   shows a schematic lens arrangement of an objective with a purely catoptric partial objective of axial symmetry

Fig 4   shows another example of the invention with a refractive, a catoptric, a second refractive partial objective in sequence.

Fig 5   shows schematically a microscope with an objective according to the invention

[0023] The example of Fig 1 is a 6 : 1 reduction objective for a scanner projection exposure apparatus of microlithography, with an image field diameter of 18.4 mm, an image side NA = 0.75, being telecentric in the object space and the image space.

[0024] All lenses are made of fluorite CaF_2 and the system is adapted for illumination by the F_2 excimer-laser at 157 mm.

[0025] Certainly modifications for other wavelengths with other materials are possible, e. g. 193 nm and quartz glass.

[0026] The first partial objective S1 is refractive and has a reduction ratio of -1/4,27.

[0027] It shows two distinct lens groups LG1 of four relatively big lenses of about 130 mm diameter, and after the aperture plane a second lens group LG 2 with significantly reduced diameter of about 80 mm and less. Here, the only aspheric lens surface is provided on surface 9 immediately subsequent to the aperture plane. Subsequent to the first intermediate image IMI 1, the second partial objective S2 is catadioptric with two opposite concave aspheric mirrors MI, M2 with central holes and two negative meniscus lenses 25, 26 and 27, 28 arranged between them. They are passed by the light beams three times. Its magnification ratio is-1/0,99.
Such a magnification ratio near unity allows for a highly symmetric construction and optimal correction of distortions.

[0028] This arrangement is particularly suitable for chromatic correction and correction of field curvature, too. Therefore even with only one lens material CaF_2 a relatively wide laser bandwith of +-1.2 pm of an unnarrowed F2-laser is accepted by this objective.

[0029] Subsequent to the second intermediate image IMI2 the third partial objective S3 again is refractive.

[0030] It takes up the divergent light beam with a strongly bent meniscus 29,30. A positive air lens - i. e. an air space in the form of a positive lens - between the lens surfaces 40 and 41 is characteristic.

[0031] With its reduction ratio of -1/1,42 the overall reduction ratio of the system is reached.

[0032] The detailed data of Table 1 show that the objective is composed of relatively few elements of limited diameters which helps for practical feasibility, as CaF_2 is very expensive and of limited availability. Also the light path in CaF_2 is limited, thus reducing the problem of significant absorption at 157 mm.

[0033] The central obscuration necessitated by the fully coaxial construction of the catadioptric second partial objective S2 is a certain drawback, as such in principle deteriorates the modulation transfer function of an objective.

[0034] However, even in common refractive projection exposure objectives a small but distinct central obscuration is entered to accomodate beam paths of alignment systems etc.

[0035] Efforts are taken in the design to keep the central obscuration small, even with mirror diameters of practical size.

[0036] It was found that the diameter of the holes in the mirrors is minimized when the chief ray height is of equal value at the two holes, but opposite in sign.

[0037] Further the mirror holes are arranged next to the two intermediate images IMI 1 and IMI 2, where the beam diameters are at a minimum. Also the first partial objective S1 has substantial image reduction to keep this hole absolutely small, so that also the total mirror diameter is limited to a practical compact value.

[0038] The mirror holes are sized to be 2,0 mm larger in diameter than the closest ray at the edge of the field.

[0039] It is recommended that a obscuration mask is inserted at the pupil (aperture) plane of the first partial objective S2 - just in front of lens surface 9. This should be sized 20,25 % in diameter - equal to 4,1 % in area. Then the area obscuration at the edge of the field has the same value as at the center and the MTF curves are completely uniform over the field.

[0040] The wavefront correction of this example is better than 0,011 waves rms over the field of 17×7 mm^2 and less than 0,009 waves rms over the field of 17×6 mm^2. The distortion is 2.4 ppm and the median shift is 10 nm.

[0041] Colour correction reaches CHL = 34 nm/pm for longitudinal colour, so that a +-1.2 pm bandwidth of an un-narrowed F2-laser can be accepted.

[0042] The example of fig. 2 and table 2 has an increased image field of 22×9 mm^2 as well as a significantly increased NA = 0,75, while the reduction ratio is changed to 5 : 1. The system is of overall similarity with the first example, but with some significant deviations.

[0043] The first refractive partial objective S1 has its aperture plane enclosed by two menisci 209, 210 and 211, 212 which are concave towards the aperture plane. Here, an obscuring disk OD is inserted for the purpose of field-independent obscuration as described above.

[0044] Two lens surfaces 209 and 217 are aspheric, the first is next to the aperture plane to affect angle deviations and the second is more in the field region.

[0045] The imaging ratio of the first partial objective S1 is -1/4,67. Therefore the catadioptric partial objective can be so small.

[0046] The second partial objective S2 again is catadioptric with two aspheric mirrors M21, M22 and two negative meniscus lenses 223,224 and 225, 226. Now their distance has strongly decreased, but angles increased in the beam path. This allows for very limited diameters of only 230 mm at the given large field and large NA. The reduction ratio is -1//0,97. In this embodiment, too, the central obscuration is 20% in diameter constant over the full field.

[0047] High NA of 0,7 at the intermediate images to allow for the small holes in the mirrors M21, M22 and a rather strong refractive power of the lenses 223,224 and 225,226 in between to give the required colour correction are specific to this example.

[0048] The mirrors M21, M22 are aspheric with maximum deviations from sphere being limited to 150 micrometers, which allows for good production and testing.

[0049] Also on the lenses between the mirrors aspheric surfaces could increase image quality. A third negative lens here would further optimize colour correction, if needed.

[0050] The third partial objective S3 shows the characteristic first meniscus lens 227,228 to be even more bent than in fig. 1. This helps for coma correction. Also the second lens 229,230 is a meniscus concave on the intermediate image IMI side, as the two final lenses 249,250 and 251,252 are menisci concave towards the image plane Im, what is preferred for aplanatism and correction of spherical aberration.

[0051] The positive air lens arranged between the lens surfaces 238 and 239 corrects the main part of spherical aberration. For this effect it is preferably arranged more in the pupil region of the objective than in a field region. However its arrangement before the pupil plane enables it to affect also the oblique spherical aberration in tangential and sagittal direction.

[0052] As a meniscus concave toward the pupil plane, lens 245,246 together with the air space created in front of it assists to the effects of the aforementioned air space.

[0053] The imaging ratio of this third partial objective S23 is -1/1,11 near unity. However, the arrangement is far from symmetry to the pupil plane, so that the strongly distorted intermediate image IMI can be transformed to a highly corrected image at the image plane Im.

[0054] Each partial objective has its part of the burden: S21 performs the reduction, S22 makes the colour and Petzval correction and S23 makes the fine tuning of imaging errors.

[0055] This second embodiment is not finely tuned to best error correction, but gives the principles of feasibility of such a design.

[0056] The aspheric surfaces of both examples of tables 1 and 2 are described by

$$z = AS2 \times h^4 + AS3 \times h^6 + AS4 \times h^8 + AS5 \times h^{10} + AS6 \times h^{12} + AS7 \times h^{10}$$

with z = axial deviation from sphere, h = radial height from optical axis.

[0057] The example of fig. 3 has a purely catoptric partial objective S31 and a purely refractive partial objective S32 between object Ob and image Im, with intermediate image IMI. This avoids the big negative lenses f the catadioptric partial objectives of the aforementioned examples. The mirrors MI, M2 now are purely used for Petzval correction - correction of field curvature.

[0058] The chromatic characteristics of the objective are defined by the refractive partial objective S32. Use of dif-

ferent lens materials allows for achromatization. For DUV/VUV excimer laser systems combinations of fluorides, namely calcium fluoride (fluorspar, fluorite), barium fluoride, strontium fluoride, NaF, Lif etc. and/or quartz glass, also in specifically doped versions, are adequate. Thus, for microlithography at 157 nm, positive lenses L1,L3 can be made of calcium fluoride and negative lens L2 can be made of barium fluoride or NaF, for example.

[0059] Naturally the refractive partial objective S32 has more lenses in a realistic microlithography or microscope objective and the lenses L1 to L3 shown are only schematic representatives.

[0060] As the refractive partial objective S32 of this catadioptric objective as compared to a full refractive system is relieved from the burden of Petzval correction, it can be simplified. The waist and bulge configuration with two and more waists of state-of-the-art refractive microlithographic reduction projection objectives is therefore not needed. Only one waist of minor beam reduction remains. Consequently the refractive partial objective S32 can be shorter, smaller in diameter and can have less lenses. Transmission and contrast are thus increased, while cost is decreased. Aspheric lens surfaces further help in this effect.

[0061] As the catoptric partial objective S31 is free of lenses, its diameter is not critical: Precision aspherical mirrors with diameters of more than one meter are state of the art in astronomy, for example.

[0062] Obviously the arrangement of catoptric and refractive partial objective also can be changed in sequence. Then the diameter of the catoptric partial system is reduced in consequence of the imaging ratio of the refractive partial objective.

[0063] For reasons of good accessibility of object Ob and image Im and of more design space for correction, it is advantageous if this system also is extended to a first refractive partial objective S41, a catoptric partial objective S42 and a second refractive partial objective S43 with intermediate images IMl1 and IMl2, as shown in the example of fig. 4.

[0064] The advantages of the first two embodiments with minimal obscuration and of the third example without big lenses between the mirrors M1, M2 can thus be combined.

[0065] Table 3 gives the design data of this example. This is a 157nm objective with all crystal lenses, most of LiF and some of NaF, giving excellent chromatic properties for an unnarrowed F_2 laser with 1,5 pm band width. Reduction ratio is 1:5, maximum image field height is 11,88 mm, NA = 0,75. Maximum lens diameter is 190,5 mm, maximum mirror diameter is 201 mm. The overall length Ob-Im is 1,459 m.

[0066] The use of crystal lenses in DUV to VUV microlithographic objectives is made here in adaptation of the earlier application DE 199 29 701.0 dated June 29, 1999 (99032 P) of co-inventor Schuster and the same assignee. This cited application as a whole shall be part of the disclosure of this application, too.

[0067] Consequently, negative NaF lenses are entered, plus one positive NaF meniscus 408, 409 in the first partial objective S41, which reduces lateral chromatic aberration, in an overall LiF lens system.

[0068] Aspheric surfaces are entered into this design at a number of surfaces, where this is advantageous. Consequently, also the mirrors 440 and 441 are aspheric.

In the first, reducing partial objective S41, the second bulge comprises one asphere, the second waist one asphere, and the third bulge 2 aspheres. In the third partial objective S43 the first bulge comprises one asphere, while the second of the two bulges comprises 2 aspheres.

[0069] The aspheric surfaces of the example of tab. 3 are described by

$$P(h) = \left(\frac{\delta * h^2}{1 + \sqrt{1-(1-EX) * \delta^2 * h^2}} \right) + C_1 h^4 + \dots + C_n h^{2n+2}$$

[0070] Where P is the height deviation as a function of the radius h (ray height with respect to the optical axis) with the aspheric constants C_1 to C_6 as given in table 3. δ is the inverse of the radius given in the table.

[0071] The objective has a high correction quality, as the wavefront error calculated for two lines of 1 pm spectral distance is less than 8 millilambda at the maximum field height and reduces to less than five millilambda on the optical axis.

[0072] The central obscuration of the system can be designed to need by enlarging distance and diameter of the mirrors 440, 441 of the catoptric partial objective S42.

[0073] Ring sector field imaging is conventional with many catoptric and catadioptric projection exposure systems of generally asymmetric construction. Such can also be realized within the invention. Then, the mirrors only need an off-axis ring sector opening for entering of the light beam, and consequently the pupil only has a two sector obscuration with further reduced effects compared to the circular central obscuration.

[0074] Fig. 5 schematically shows a microscope with an objective according to the invention.

[0075] As such primarily makes sense for a DUV/VUV inspection microscope, direct visual observation by an ocular is not shown, but an image detector CCD of any appropriate known sort is provided in the image plane of the objective.

The objective is constituted by two refractive partial objectives S51, S53 and the intermediate catoptric or catadioptric partial objective S52. The example shows two coaxial opposite mirrors M1, M2 and one negative lens L in it.

[0076] The design of the objective is generally as shown in the embodiments described above, but with image and object plane exchanged to obtain magnification, and with higher imaging ratio and smaller field.

[0077] An illumination system III illuminates the object Ob appropriately.

Table 1

0,75 N.A., -2= 157 nm, β = 6X, 17 x 7 mm double-telecentric			
Element	RADIUS [mm]	THICKNESS [mm]	APERTURE RADIUS [mm]
OB	--	41.365	
1	207.804	15.0000	64
2	7154.0	85.7060	
3	-148.152	10.000	60
4	-480.523	27.979	
5	275.460	21.000	68
6	-420.424	18.169	
7	91.168	20.000	62
8	231.534	102.963	
9	-62.100	5.000	25
10	551.104	10.065	
11	-77.910	9.000	32
12	-47.566	1.000	
13	-281.444	12.500	41
14	-83.966	1.000	
15	-1256.9	17.000	43
16	-69.116	1.000	
17	99.668	7.000	40
18	60.790	0.978	
19	63.022	18.000	37
20	-177.094	1.000	
21	65.632	5.000	
22	43.522	9.388	
23	44.597	7.000	23
24	115.690	20.474	
IMI1	--	-5.072	
M2	220.905	16.140	115
25	349.084	11.500	112
26	150.213	131.449	
27	-163.770	11.500	105
28	-381.158	17.158	
MI	-228.356	115	
29	-42.092	21.059	35
30	-51.728	1.000	
31	-194.937	18.000	59
32	-113.392	1.000	
33	-1132.0	18.000	70
34	-193.134	1.000	
35	458.425	18.000	74
36	-386.456	93.349	
37	171.069	27.160	78

6

Table 1   (continued)

Element	RADIUS [mm]	THICKNESS [mm]	APERTURE RADIUS [mm]
38	-1302.6	1.000	
39	115.683	12.796	71
40	79.902	53.335	
41	-108.436	37.180	61
42	-140.231	1.000	
43	171.662	24.000	71
44	-1877.0	29.921	
45	-118.760	37.456	66
46	-131.389	1.000	
47	153.982	21.000	73
48	1445,6	1.049	
49	72.396	20.001	59
50	76.113	1.000	
51	53.654	49.996	49
52	69.967	16.341	
IM	--	--	

[0078]   Aspheric Surface Data
9: ASO = 0 A   S 1 = 0   AS2 = -1.6880e-06
AS3 = 1.5172e-10
        AS4 = -1.1366e-12/AS5 = 1.3050e-16/AS6 = 1.7402e-18
AS7 = -2.4094e-21
M1: ASO = 0   AS1 = 0   AS2 = -2.1332e-09
AS3 = -1.157e-13
        AS4 = -2.4958e-18/AS5 = 2.735e-23/AS6 = -7.4436e-27
AS7 = 1.5059e-31
M2: ASO = 0   AS1 = 0   AS2 = 1.7841e-09
AS3 = 6.8616e-14
        AS4 = 3.6976e-18/AS5 = 5:2619e-23/AS6 = -2.331e-27
AS7 = 2.8845e-31
M1, M2 central hole r = 15,3 nm
[0079]   Index of refraction CaF_2 at 157 nm: n = 1,55971

Table 2

5X, .75 N.A., 22 X 9 mm, λ = .157µm			
Element	RADIUS [mm]	THICKNESS [mm]	APETURE RADIUS [mm]
OB	Telecentric	34.000	
201	170.721	15.000	73
202	183.404	70.512	
203	-88.583	10.000	72
204	-109.418	0.097	
205	489.985	31.998	86
206	-223.861	105.847	
207	211.214	18.000	80
208	1008.7	132.111	
209	98.261	7.000	38
210	75.231	9.337	
OD	--	6.429	obscuring disk

Table 2   (continued)

Element	RADIUS [mm]	THICKNESS [mm]	APETURE RADIUS [mm]
			r = 6,75 mm
211	-105.403	28.061	35
212	-103.952	1.000	
213	2546.4	21.782	56
214	-129.850	1.000	
215	459.497	25.167	59
216	-117.119	1.000	
217	76.297	7.000	50
218	52.636	5.014	
219	60.098	27.883	45
220	-254.989	1.000	
221	158.480	18.301	38
222	-1889.6	19.412	
IMI		-4.449	
M2	198.917	11.198	115
223	249.698	11.500	115
224	141.621	95.251	
225	-146.113	11.500	105
226	-279.951	14.507	
M1	-195.876126		115
IMI2	--	27.988	
227	-29.245	26.188	28
228	-38.617	1.000	
229	-212.943	16.904	64
230	-108.498	1.000	
231	-1195.7	19.000	74
232	-186.309	1.000	
233	397.280	24.000	82
234	-447.100	40.123	
235	184.325	28.000	82
236	-5827.0	1.000	
237	94.479	15.000	71
238	73.235	52.490	
239	-84.776	10.000	58
240	-134.685	0.997	
241	548.320	30.000	72
242	-202.022	1.370	
243	244.314	24.000	71
244	-390.876	9.997	
245	-154.779	26.099	69
246	-221.429	1.000	
247	170.308	27.000	69
248	5689.0	1.000	
249	82.493	29.706	58
250	66.456	1.000	
251	38.604	31.198	38
252	74.002	16.468	
IM	--	--	11.9

[0080]   Aspheric Surface Data

EP 1 098 215 A1

Surface 209
ASO = 0   AS1 = 0   AS2 = -1.9059e-17
AS3 = 5.2904e-10/AS4 = -2.9602e-13/AS5 = 2.9727e-16
AS6 = -3.3981e-19/AS 7 = 3.3504e-23

Surface 217
ASO = 0   AS1 = 0   AS2 = -2.7436e-07
AS3 = -1.1707e-12/AS4 = -1.1841e-14/AS 5 = 1.8131e-17
AS6 = -7.5053e-21/AS7 = 1.3749e-24

Surface M1
ASO = 0   AS1 = 0   AS 2 = 1.9405e-09
AS3 = 9.5605e-14/AS4 = -2.6910e-17/AS5 = 5.9514e-23
AS6 = -7.7031e-26/AS7 = 1.8364e-30

Surface M2
ASO = 0   AS1 = 0   AS2 = 3.2910e-09
AS3 = 1.4964e-13/AS4 = -1.2351e-17/AS5 = 2.4844e-21
AS6 = -1.9615e-25/AS7 = 6.7644e-30

[0081]   M1, M2 central hole r = 15,5 mm

Table 3

SURFACE	RADI I	THICKNESS	MATERIAL
Ob		31.542	
402	161.992	15.188	LiF
403	469.503	19.672	
404	231.249	8.649	LiF
405	323.701	81.163	
406	-125.044	7.000	LiF
407	1233.917	29.038	
408	-136.3150	28.504	NaF
409	-110.661	42.406	
410	166.198	38.763	LiF
411	-426.980	33.045	
412	102.987	42.894	LiF
413	-497.639	3.533	
414	-344.154	7.000	NaF
415	110.870	62.455	
416	-313.200	7.000	LiF
417	306.167	12.322	
AS1	∞	4.589	
419	-294.9867	7.21	NaF
420	139.1333	10.42	
421	-198.121	17.91	LiF
422	-67.419	.7642	
423	-423.496	14.9924	LiF
424	-117.918	.8112	
425	743.808	8.0149	NaF
426	123.869	.9171	
427	128.249	44.3083	LiF
428	-90.153	.8501	
429	230.303	11.2449	LiF

9

Table 3 (continued)

SURFACE	RADI I	THICKNESS	MATERIAL
430	1688.121	1.1630	
431	122.245	7.9843	NaF
432	59.579	.7500	
433	60.793	24.9206	LiF
434	-934.252	1.1385	
435	87.724	10.9289	LiF
436	74.6528	7.4167	
437	43.171	13.3010	LiF
438	47.425	5.000	
IMI1	∞	135.0601	
440	-248.671	-135.,0601	
441	243.629	135.2019	
IMI2	∞	21.4887	
443	-39.71329	27.9107	LiF
444	-53.040	2.7851	
445	-218.179	26.3722	LiF
446	-100.461	2.5410	
447	-444.958	33,4544	LiF
448	-125.627	3.4864	
449	205.875	52.0553	LiF
450	-445.534	3.1476	
451	-393.14835	7.1061	NaF
452	529.85954	10.9028	
453	171.69804	54.8263	LiF
454	-3285.94521	2.9859	
455	1249.94523	10.7714	NaF
456	188.56505	53.9985	
457	-102.09026	18.5249	LiF
458	-114.02167	3.1811	
459	-108.06602	36.3405	LiF
460	-122.25579	.8148	
461	237.93896	30.4791	
462	-591.44374	33.9271	
463	-131.73596	9.2936	NaF
464	-816.022	4.0340	
465	-921.759	43.70	LiF
466	-161.952	12.96	
467	135.682	35.56	LiF
468	485.873	7.77	
469	74.486	26.357	LiF
470	88.618	3.623	
471	64.861	56.517	LiF
472	65.449	20.524	
Im	∞		

[0082]   Aspheric constants

11 A	C1 .43635053E-07	C2 -.10565814E-11	C3 .33243511E-16
	C4 -.27930883E-20	C5 .11432015E-24	C6 -.33257819E-29

(continued)

19 A	C1 -.96601935E-06	C2 .70267826E-10	C3 .31115875E-13
	C4 -.43329420E-17	C5 -.41852201E-20	C6 .30053413E-25
25 A	C1 -.29611487E-07	C2 .20760499E-10	C3 -.12518124E-14
	C4 -.52770520E-18	C5 .86996061E-22	C6 -.19792693E-27
34 A	C1 -.15885997E-06	C2 .52924012E-10	C3 -.73552870E-14
	C4 -.86379790E-18	C5 .59324551E-21	C6 -.39153227E-25
40 A	C1 .23060301E-07	C2 .81122530E-13	C3 -,32179819E-17
	C4 .71766836E-21	C5 -.46055104E-26	C6 .12956188E-31
41 A	C1 -.11072232E-07	C2 .31369498E-13	C3 .77375306E-17
	C4 19892497E-21	C5 -.89740115E-26	C6 .68627541E-31
49 A	C1 .56699275E-08	C2 .57127904E-12	C3 .59227712E-16
	C4 .21077816E-20	C5 .15595431E-24	C6 -.13690607E-29
63 A	C1 -.17174244E-07	C2 .18573484E-11	C3 -.42802250E-16
	C4.51394491E-20	C5-.37650847E-24	C6 .22638360E-28
68 A	C1 .10650246E-07	C2 .20265609E-11	C3-.88014450E-16
	C4 .91073382E-20	C5 -.55181052E-24	C6 .37391374E-28

Claims

1. A catadioptric objective of axial symmetry comprising two intermediate images.

2. A catadioptric objective comprising two refractive partial objectives and one catadioptric partial objective.

3. An objective comprising

    a first partial objective,
    a first intermediate image,
    a second partial objective,
    a second intermediate image,
    a third partial objective,
    wherein at least one of said partial objectives is purely refractive.

4. An objective comprising at least

    a first partial objective,
    an intermediate image,
    a second partial objective,
    one of said partial objectives being purely refractive and one being purely catoptric.

5. An objective according to a combination of at least two of the claims 1 to 4.

6. An objective according to at least one of claims 1 to 5, characterized in that it comprises a partial objective with two opposing concave mirrors with central bores, and with an optical axis, said concave mirrors being arranged axially symmetric with respect to said optical axis, their concave surfaces facing each other.

7. An objective according to claim 6, wherein
each of said concave mirrors has a vertex situated on said optical axis, and wherein each of said intermediate images has a maximum image height and is given on a surface with a piercing point on said optical axis, and at least one of said vertici is distant from at least one of said piercing points by a distance less than the maximum image height of the image having said piercing point.

8. An objective according to claim 6 or 7, wherein
at least one lens is arranged in the beam path between the two concave mirrors.

9. An objective according to claim 8, wherein said at least one lens has negative refractive power.

10. An objective according to at least one of claims 6 to 9, wherein
said concave mirrors have central openings with a radius, each of said radii being no greater than 1,5 times the maximum image height of the neighbouring intermediate image.

11. An objective according to at least one of claims 6 to 10, wherein
each of the radii of said central openings is less than 25 % of the maximum light beam height at said concave mirror.

12. An objective according to at least one of claims 6 to 11, wherein
the light beam has a chief ray height at each of the bores, which is of equal value but opposite sign at the two bores.

13. An objective according to at least one of claims 1 to 12, wherein

    a first refractive partial objective,
    a partial objective comprising at least one mirror, and
    a second refractive partial objective
    are arranged in sequence.

14. An objective according to at least one of claims 1 to 13, wherein
at least one lens of said refractive partial objectives has an aspheric surface.

15. An objective according to at least one of claims 1 to 14, wherein
at least one of said partial objectives comprises a diffractive optical element.

16. An objective according to at lest one of claims 1 to 15, wherein
said partial objective comprising at least one mirror has a magnification ratio in the range between -1/0,7 and-1/1,3.

17. An objective according to claims 13 and 16, wherein
the first refractive partial objective has a magnification ratio of -1/3 to -1/8.

18. An objective according to claims 13 and 16 or to claim 17, wherein
the second refractive partial objective has a magnification ratio of -1/0,8 to -112.

19. An objective according to at least one of claims 1 to 18, wherein
at least one of the first and second refractive partial objectives consists of a first positive lens group, a negative lens group and a second positive lens group.

20. An objective according to at least one of claims 1 to 19, wherein
said negative lens group comprises at least two negative menisci, their concave surfaces facing each other.

21. An objective according to claim 19 or 20, wherein
at least one of said first and second positive lens groups comprises at least four positive lenses.

22. An objective according to at least one of claims 1 to 21, wherein
all lenses contained are made of the same material, preferably a fluoride crystal.

23. An objective according to at least one of claims 4 - 21, wherein lenses are made from at least two different fluorides.

24. An objective according to at least one of claims 1 to 23, wherein
the image field is an off-axis ring sector.

25. An objective according to at least one of claims 1 to 24, wherein the first partial objective has a pupil plane and a central obscuration device is located near said pupil plane.

26. An objective according to at least one of claims 1 - 25 wherein at least one of the refractive partial objectives has at least a first lens group and a second lens group, one of them having lesser lens diameters.

27. An objective according to claim 14 and claim 26, wherein the at least one aspherical lens surface is on a lens of the lens group with lesser lens diameters.

28. An objective according to at least one of claims 1 to 27, wherein the third partial objective has at least one positive concave air lens-near its pupil plane, namely located at a distance from the second intermediate image of between 25 % and 75% of the length of this partial objective.

29. An objective according to at least one of claims 1 - 28, wherein the image side partial objective has two first lenses subsequent to the second intermediate image, which are menisci concave on the side of the intermediate image, and two last lenses adjacent to the image, which are menisci concave on the side of the image.

30. An objective according to at least one of claims 1 to 29, wherein the image side partial objective has a pupil plane and at least one lens arranged at a distance from the image plane of between 25 % and 75 % of the length of the image side partial objective is a meniscus concave toward the pupil plane.

31. A microscope comprising an objective according to at least one of claims 1 to 30.

32. A microlithographic projection exposure apparatus comprising a projection objective according to at least one of claims 1 to 30.

33. Use of a projection objective according to at least one of claims 1 to 30 for microlithographic projection exposure.

34. Method of microlithographic structuring of a substrate comprising the step of illuminating a mask with VUV light and projecting an image of said mask onto said substrate through a projection objective according to at least one of claims 1 to 30.
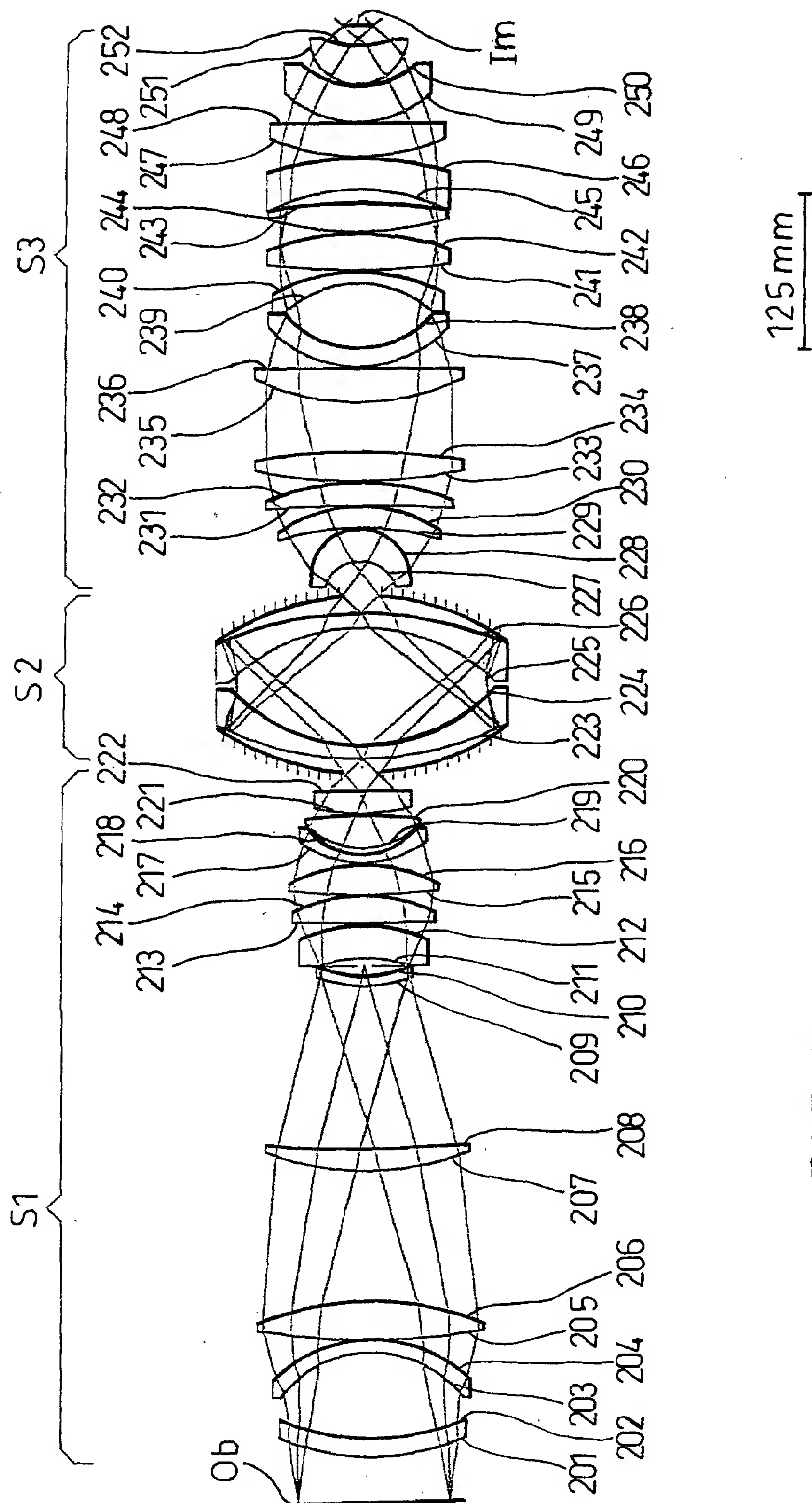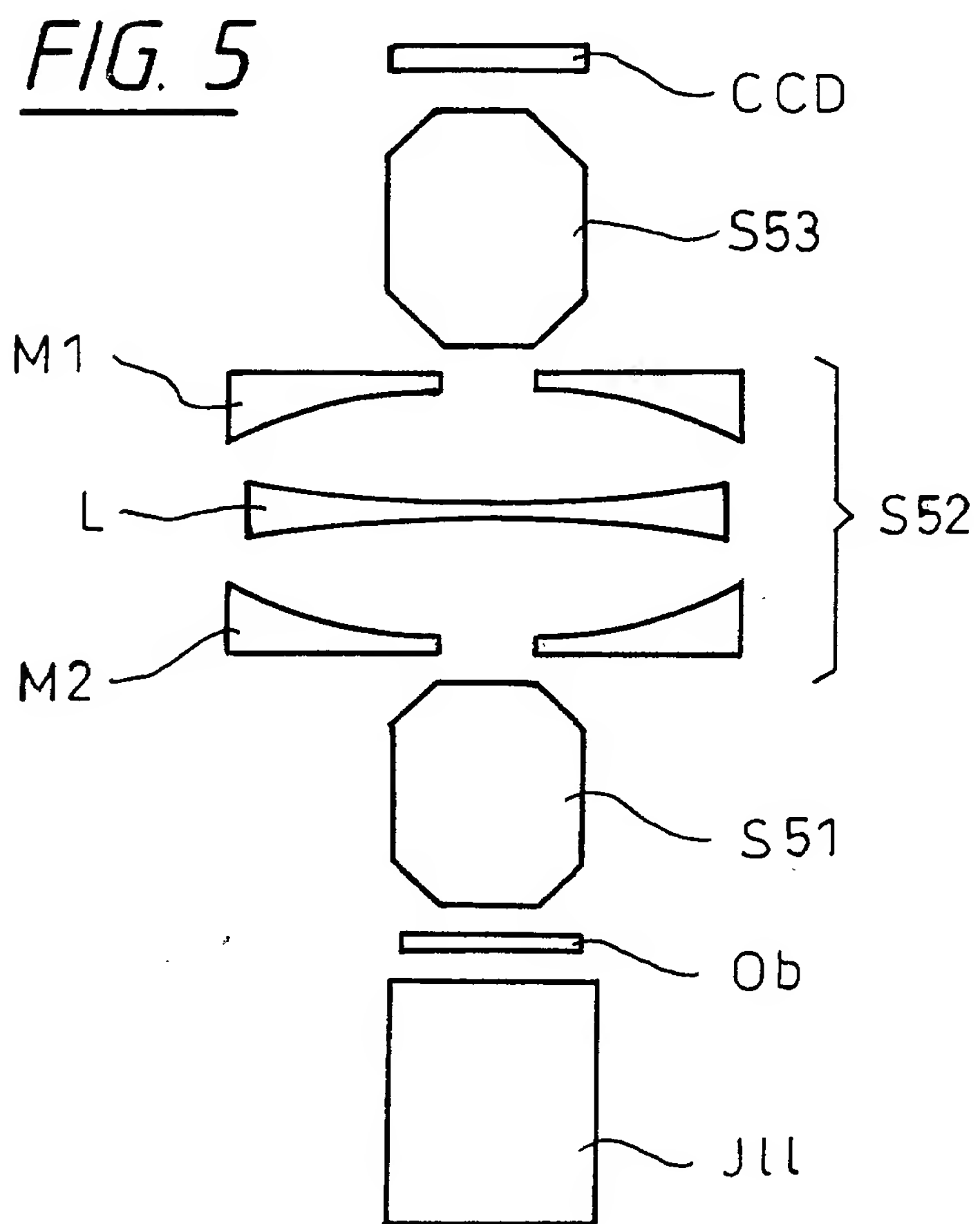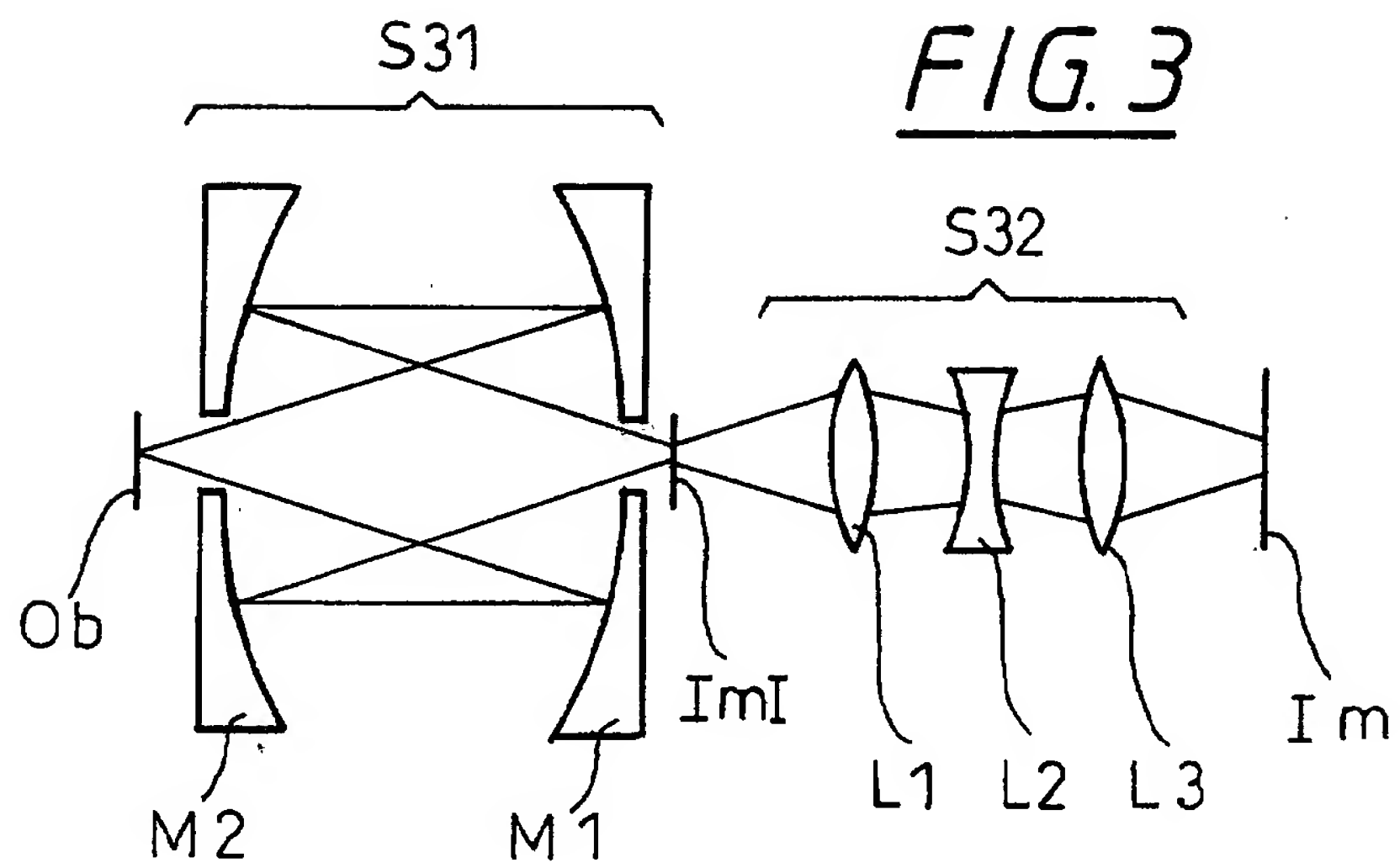
FIG. 1

125 mm

EP 1 098 215 A1

FIG.2

125 mm

15

FIG. 3

S31

S32

Ob

ImI

M2   M1

L1 L2 L3   Im

FIG. 5

CCD

S53

M1

L

M2

S52

S51

Ob

Jll

FIG.4
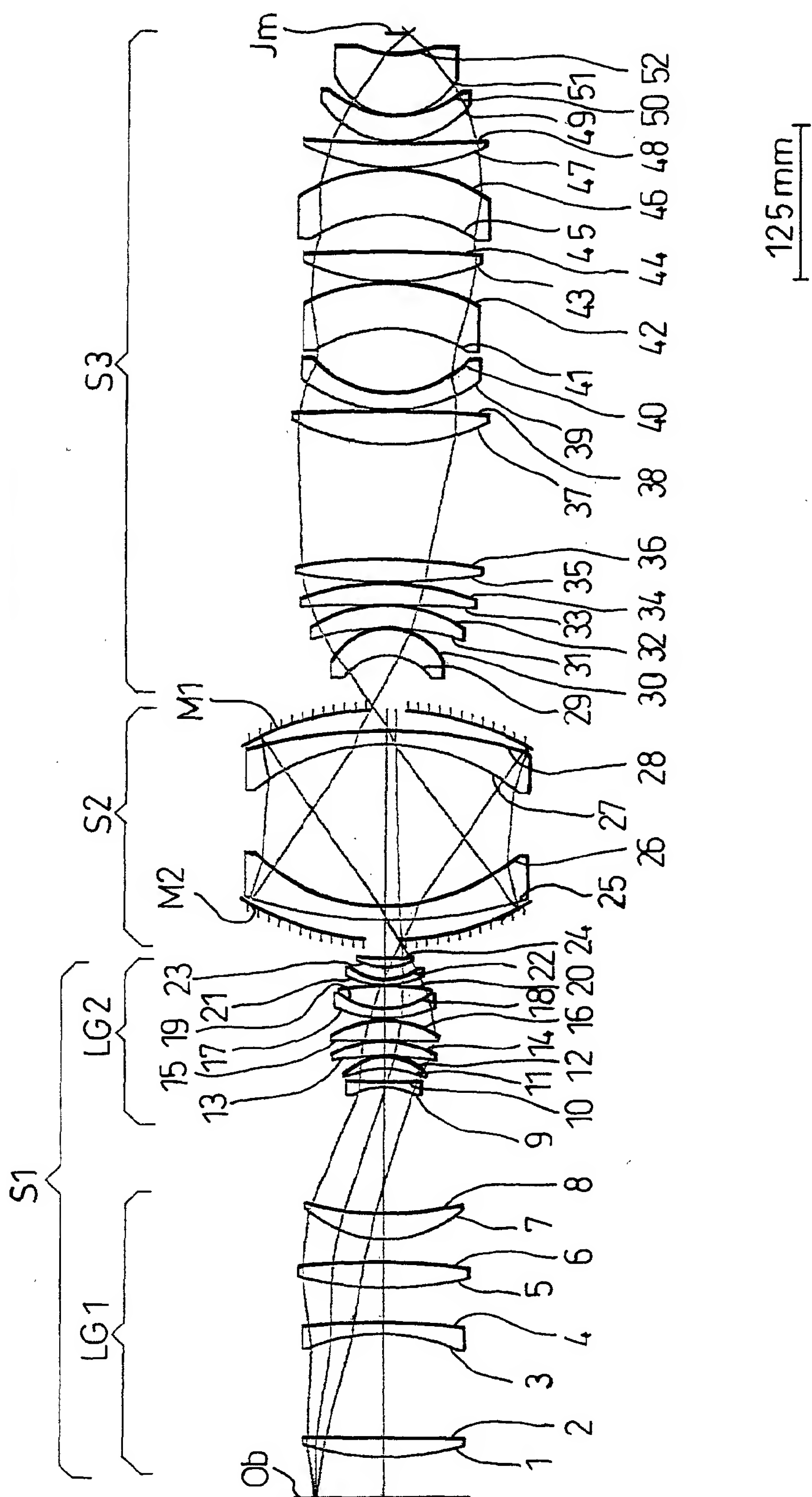
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Application Number

EP 00 12 2738

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	12 February 2001	Hylla, W

EPO FORM 1503 03.82 (P04C01)

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ON EUROPEAN PATENT APPLICATION NO.

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